R-θ Actuator Development at LBNL

Christoph Schenk, Joe Silber, Danny Zhou, Rodney Post, Mario Cepeda

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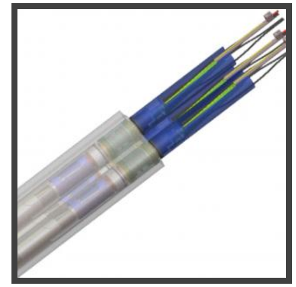
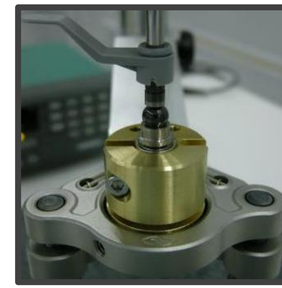
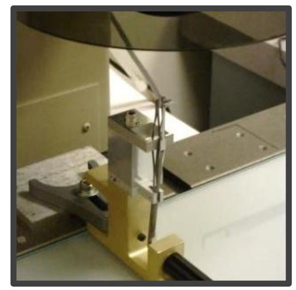
Tucson Collaboration Meeting

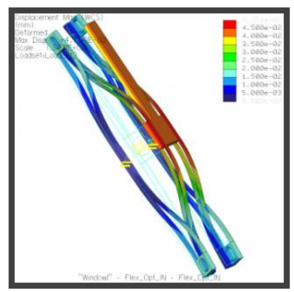
Outline

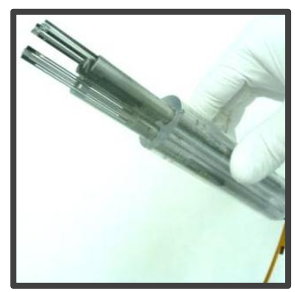
- R-θ positioner concept
- Component testing and optimization:
  - Bearing cartridge for θ-stage
  - Linear flexure stage
- Prototype progress



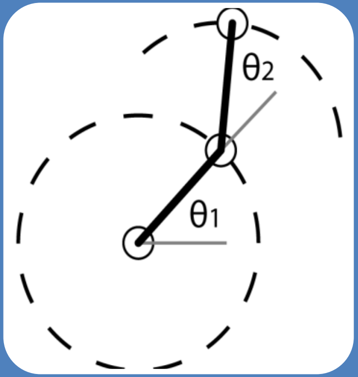






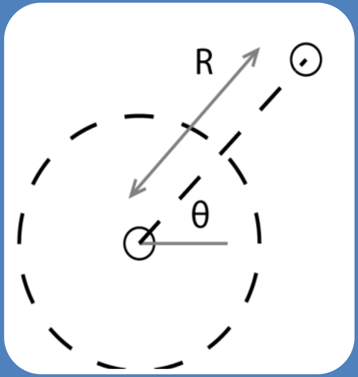


Kinematic Approaches



θ-θ

- 2 rotational axes to align during fiber mounting
- Uses well-established mechanisms (LAMOST, COBRA, SIDE…)
- Likely more stiffly constrained against defocus
- Blind spot in center for any mismatch in arm length



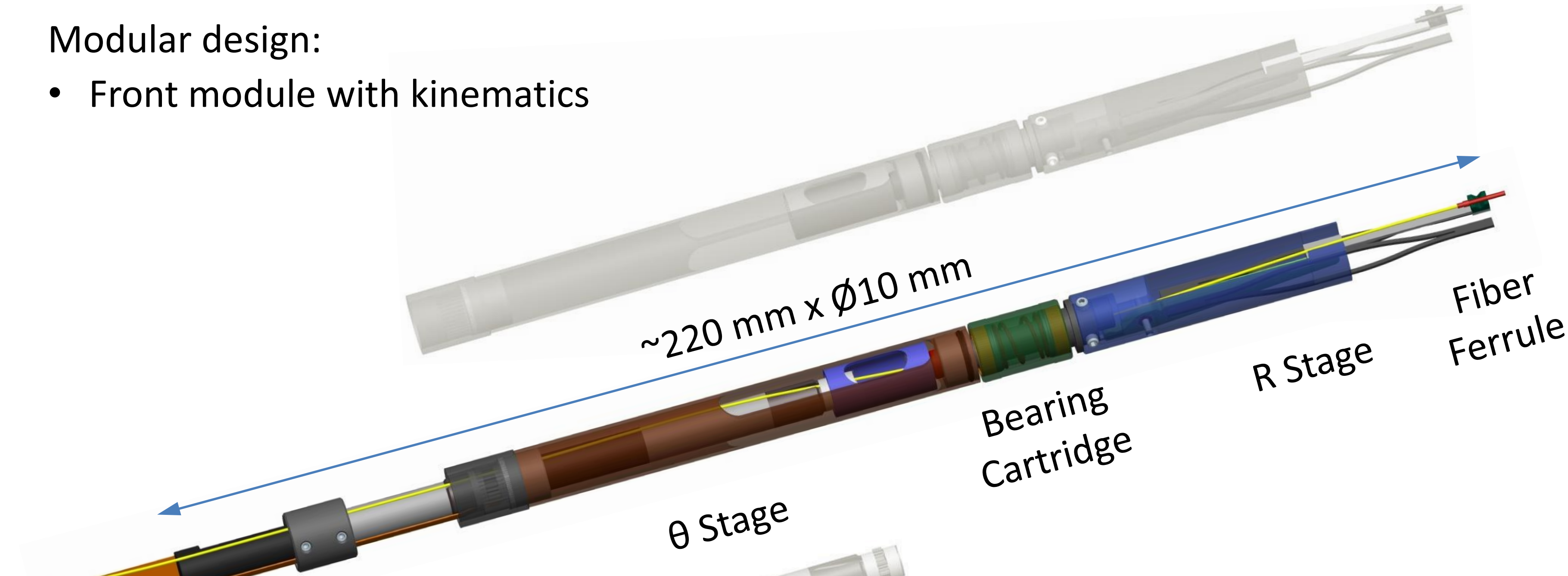
R-θ

- 1 rotational axis to align during fiber mounting
- Overtravel capability (beyond spec patrol radius)
- Simpler anti-collision algorithms
- Blind spot in center for any de-centering of R axis

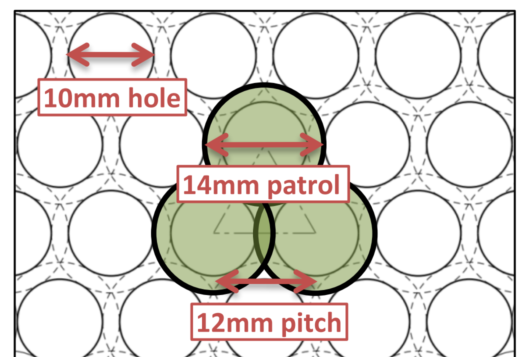
R-θ Positioner Concept

Modular design:

- Front module with kinematics

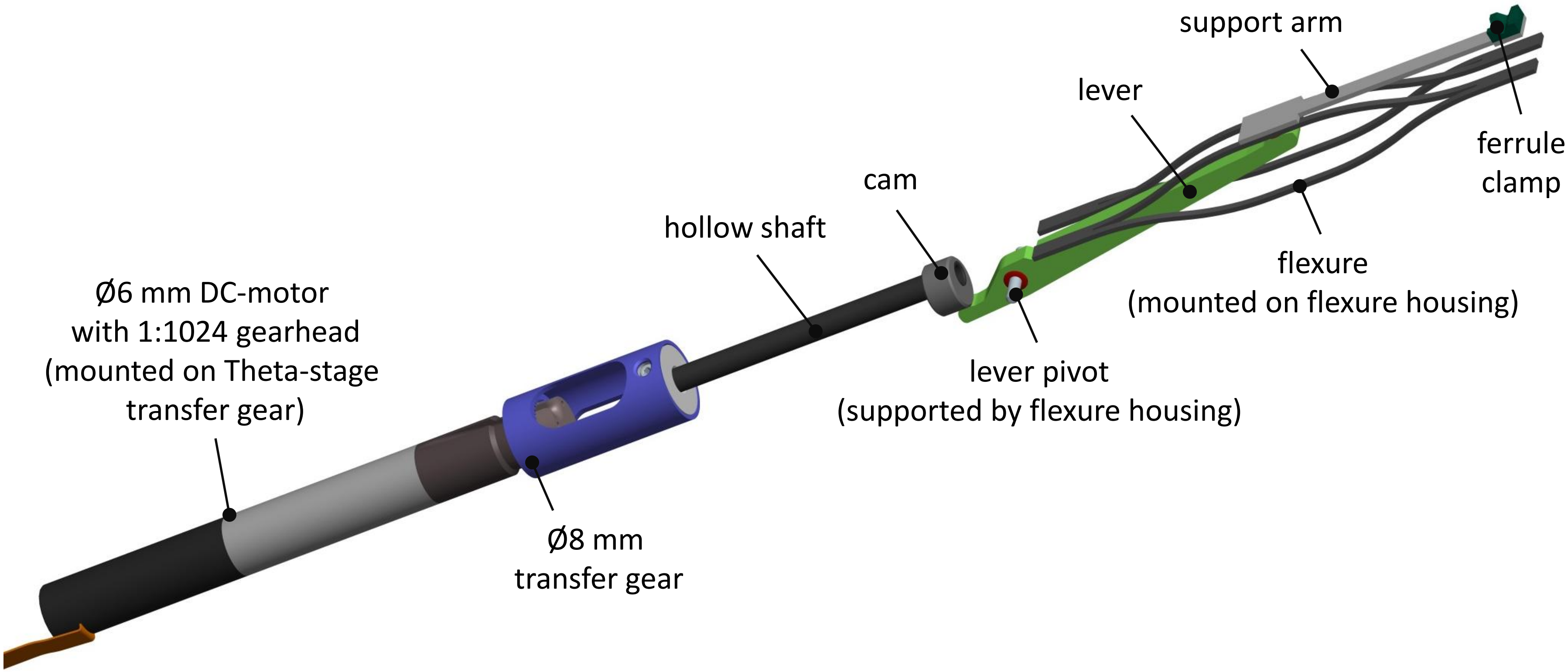


- Rear module with stationary drives for both axes and driver electronics



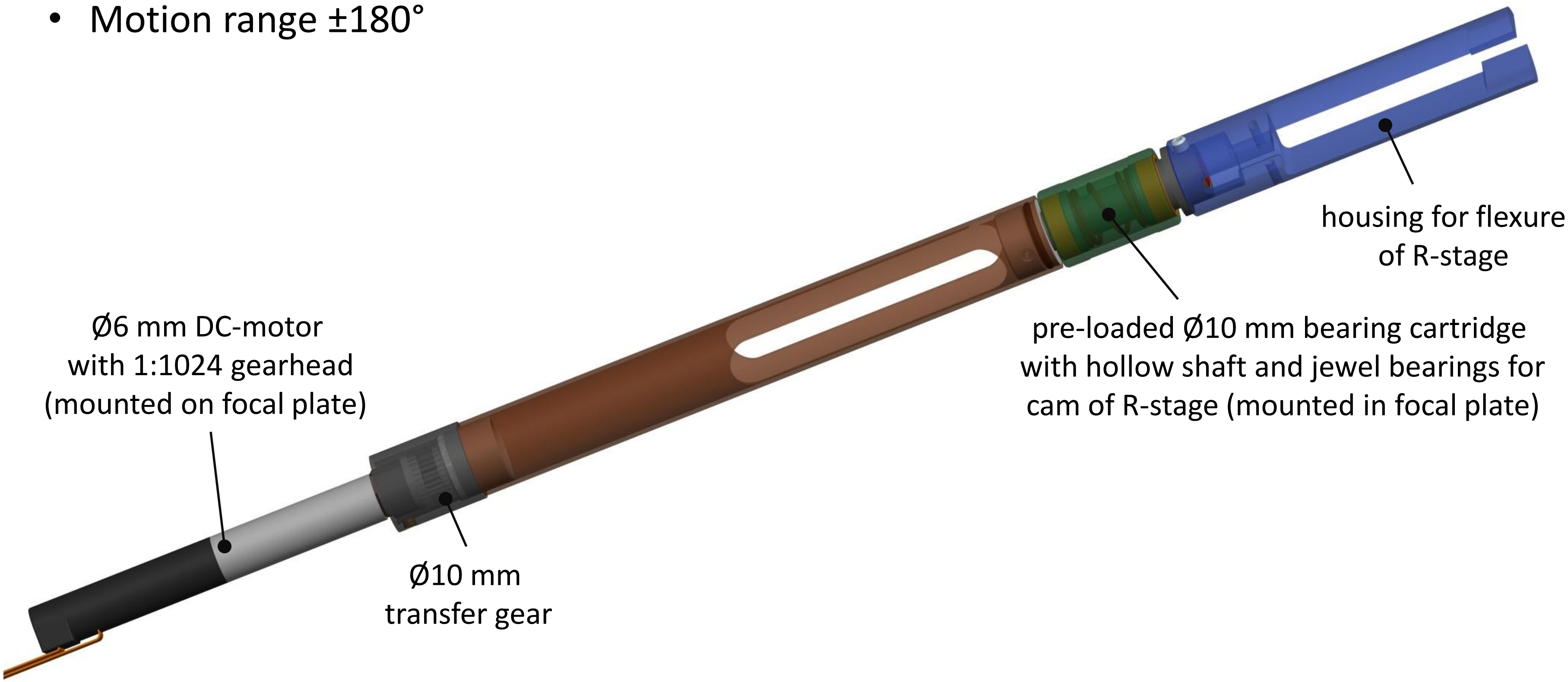
R-Stage

- Flexure acts as an extensible linear bearing with spring-like mechanical pre-load
- Motion range: 8 mm (7.5 mm + 0.5 mm pre-load for flexure)
- Unrestricted rotation of cam (no risk of fiber damage)



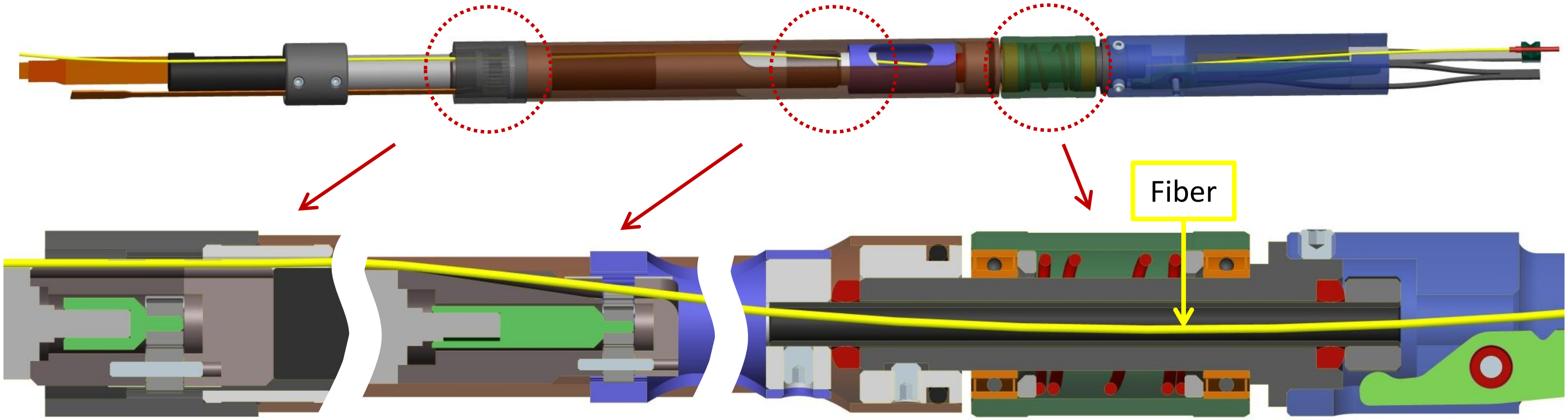
θ-Stage

- θ-Stage is built around R-stage
- Interfaces to focal plane at bearing cartridge
- Motion range ±180°

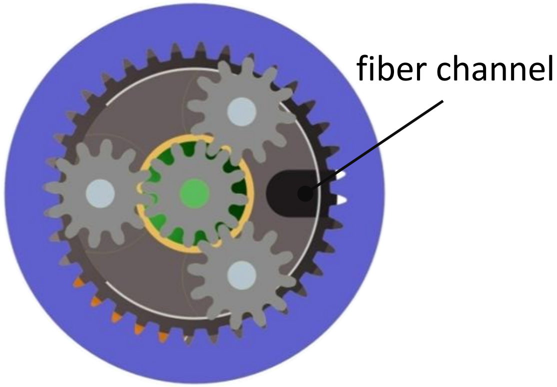


Fiber Path

- Fiber runs sideways along the rear module, laterally constrained by channels to avoid collisions with gears
- Passes through the hollow shaft of cam and bearing cartridge



- transfer gear similar to planetary gear but with *pinned* planets allows bypass channels for fiber and wires
- easy penetration of rotational mechanical coupling with 360° freedom



Position Accuracy Requirements

Deviations diminish total light throughput:

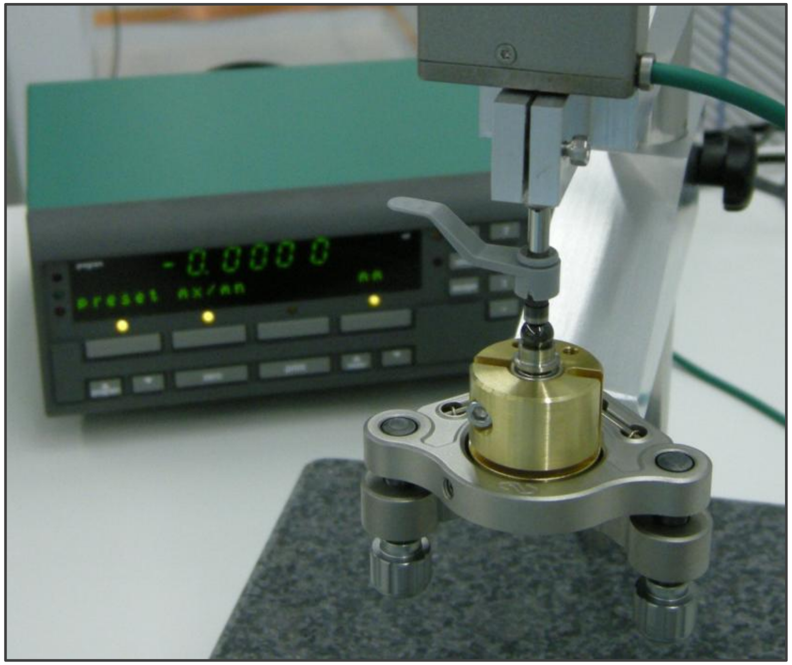
- ±15 µm lateral ⇨ errors can be compensated (resolution, closed loop control)
- ±15 µm defocus ⇨ errors *can not* be compensated
- ±0.5° tilt accuracy ⇨ errors *can not* be compensated

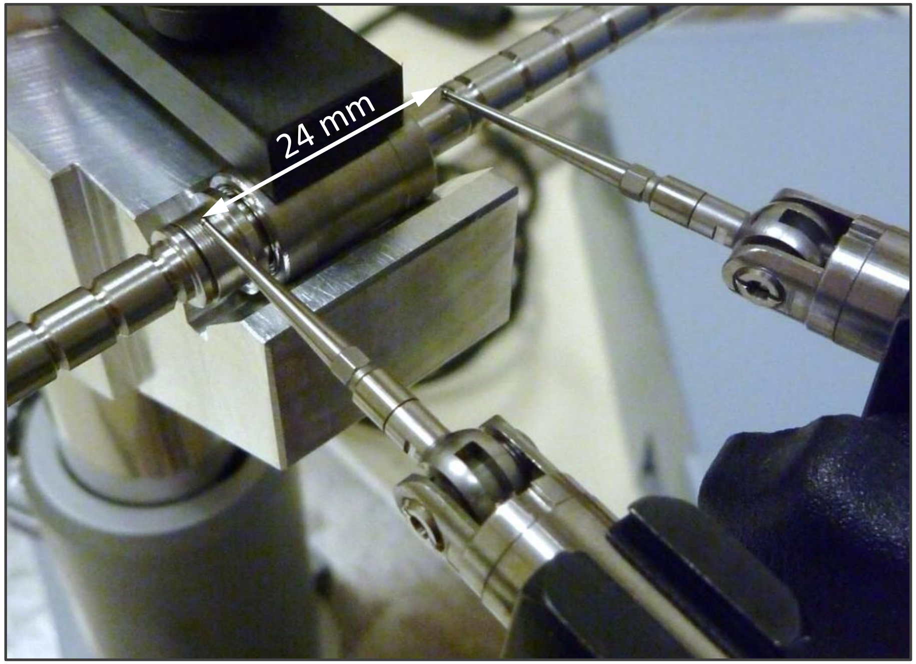
	Item	Error µm	Ref base mm	Tilt Angle deg	
1	Focal plate hole precision	25	100	**0.014**	**1. Axis**
2	Mounting error of bearing cartridge of 1st Θ-axis in focal plate	10	15	**0.038**	
3	Tilt of shaft in sleeve of bearing cartridge of 1st Θ-axis	8	15	**0.031**	
4	Tilt caused by run-out of shaft of bearing cartridge of 1st Θ-axis	8	20	**0.023**	**2. Axis**
5	Mounting error for stack mounted on bearing cartridge shaft of 1st Θ-axis (Interface part for drive and bearing of 2nd Θ-axis)	20	50	**0.023**	
6	Mounting error of bearing cartridge of 2nd Θ-axis in interface part	10	15	**0.038**	
7	Tilt of shaft in sleeve of bearing cartridge of 2nd Θ-axis	8	15	**0.031**	
8	Tilt caused by run-out of shaft of bearing cartridge of 2nd Θ-axis	8	20	**0.023**	**3. Axis**
9	Mounting error of ferrule clamp on shaft of bearing cartridge of 2nd Θ-axis	10	6	**0.095**	
10	Mounting error of ferrule in ferrule clamp	7	6	**0.067**	
11	Fiber alignment in ferrule			**0.050**	
12	Fiber tip polishing			**0.050**	
13	Pointing error (flat patrol disc) (7 mm patrol radius, radius of curvature of focal plane 2.7 m) (0.1° for 4 m curvature)	7000	2700	**0.149**	

Sum	**Total**	0.63
SQRT(Sum of squared arguments)		0.22
Combined		**0.40**

Bearing Cartridge Tests

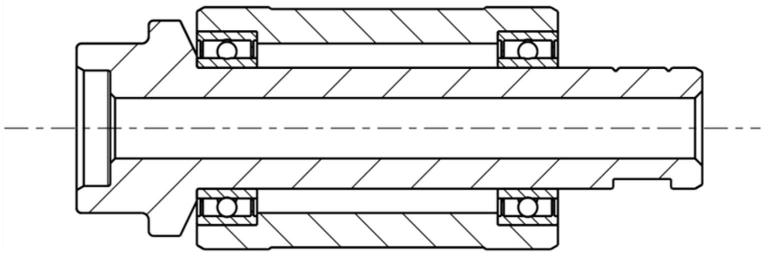
- Custom bearing cartridge from NMB Minebea (20 pcs.)
  - 2 shielded standard bearings OD 8 mm / ID 5 mm, ABEC 5, 2.5…7.5 µm radial clearance
  - distance between bearings: 12.5 mm
  - 5 N axial pre-load
- Different measurement setups with sub-micron resolution / accuracy





Results of Cartridge Tests

- Axial and radial displacement during spinning
- Axial and radial stiffness
- Tilt of nominal shaft axis
- Resistance to torque
- Long-term spinning tests

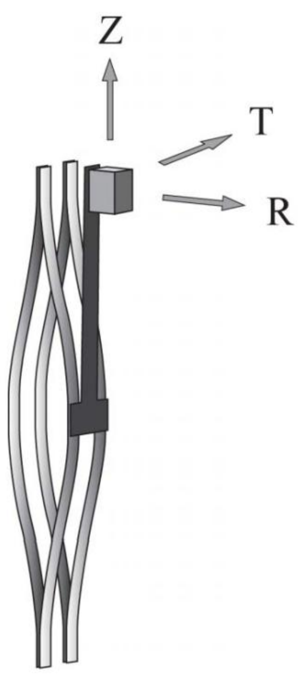


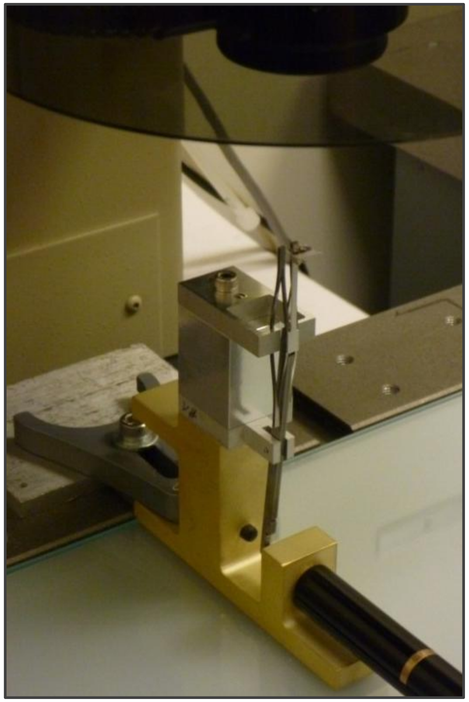
	Min	Max	Average	Unit	Notes
Axial Displacement	0.0	1.0	**0.4±0.2**	μm	0.5…3.5 N axial load
Tilt of nominal shaft axis	0.007	0.032	**0.019±0.007**	deg	roundness of sleeve included
Tilt due to radial run-out of shaft	0.006	0.018	**0.013±0.004**	deg	roundness of shaft included
Torque resistance	4.6E-05	5.8E-05	**5.0E-05±0.8E-05**	deg/Nmm	40…120 Nmm load
Radial stiffness			**>8**	N/μm	-4…+4 N radial load
Axial stiffness	measurements ongoing				

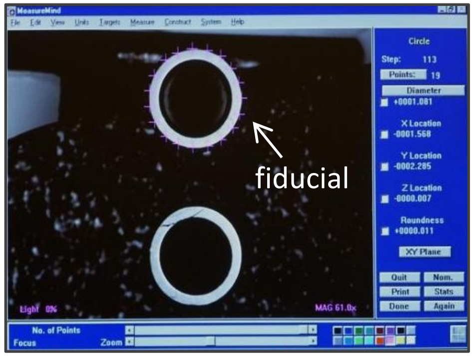
- Tilt errors can be probably reduced by increasing cartridge length
- Measurement results confirm estimates of tilt tolerance budget so far

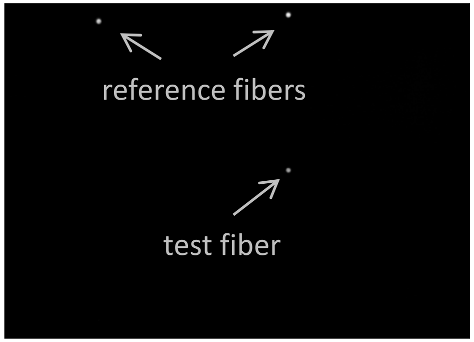
Flexure Tests

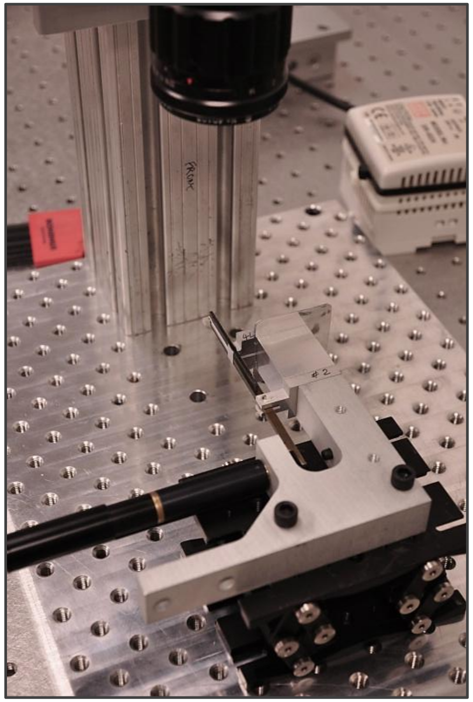
- Measurement setups:
  – Camera based position analysis of back-illuminated fiber tip
  – Smart Scope (optical tracking of fiducial marks)
- Defocus (Z) and transverse (T) errors of flexure (isolated from positioner)
- R, θ, (Z) positioning accuracy within patrol area of positioner





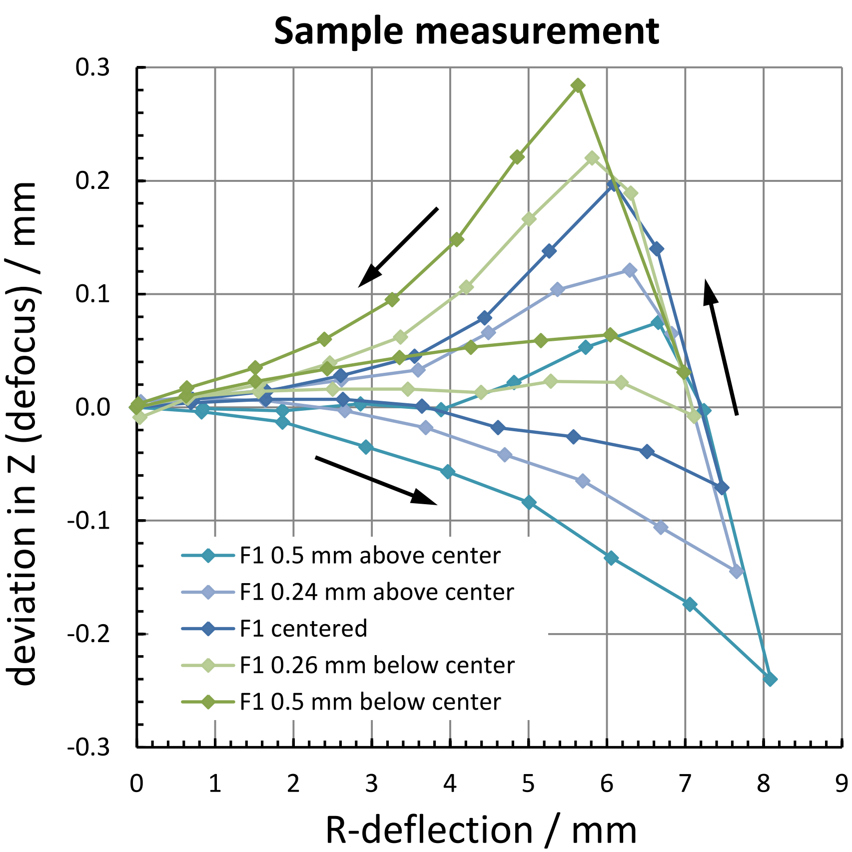


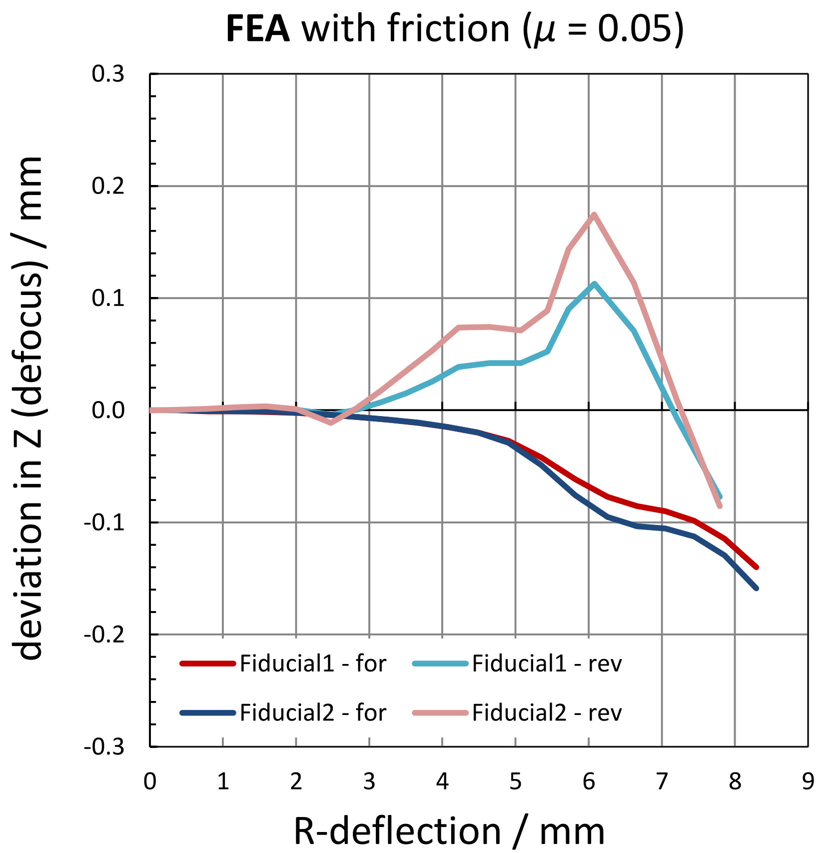




Measurement Results Defocus

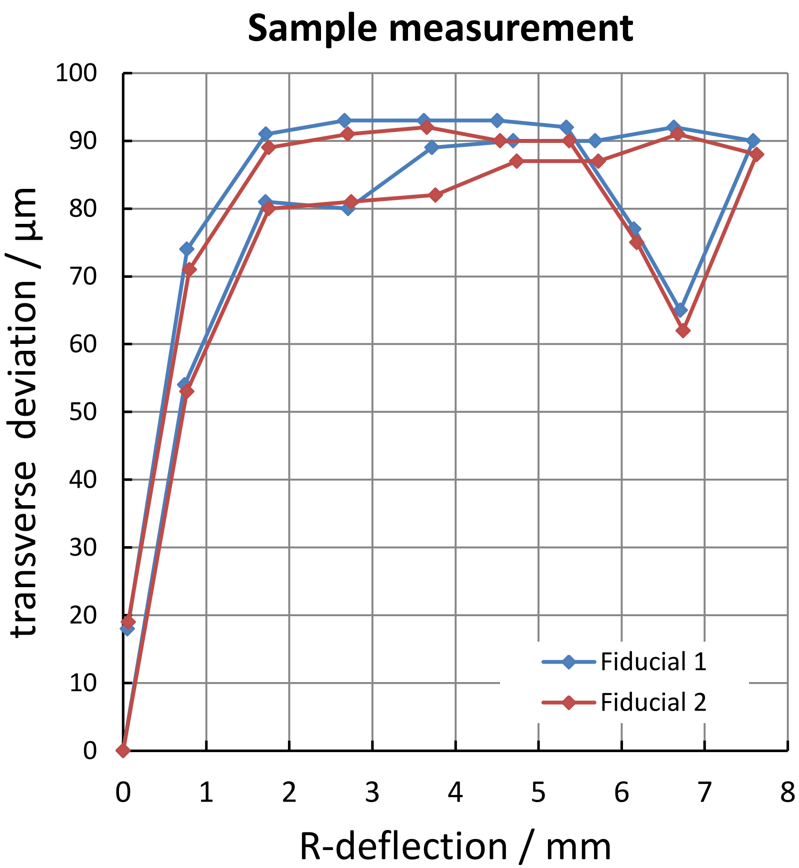
- Huge leap in deviation at beginning of reverse stroke (270 µm on average)
- FEA model can be finally constraint with physical test data to improve performance for next flexure revision

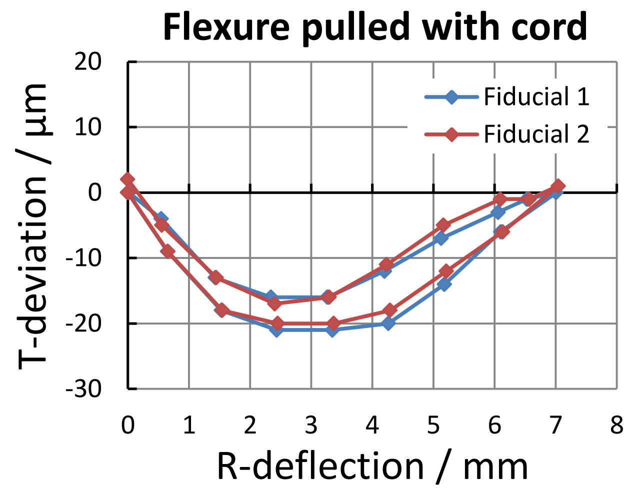


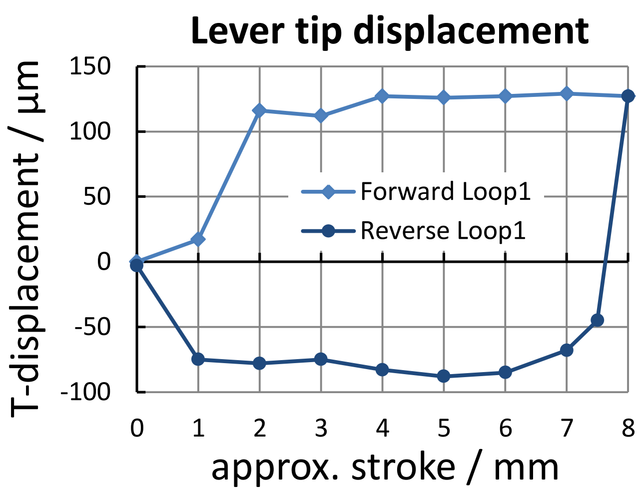


Measurement Results Transverse Deviations

- Transverse deviations of flexure also very high

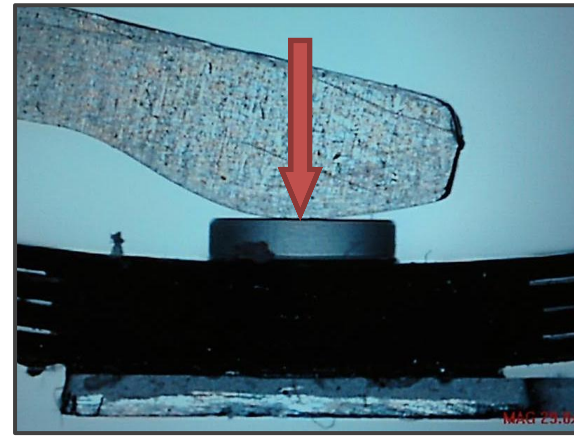






Conclusions from Measurements

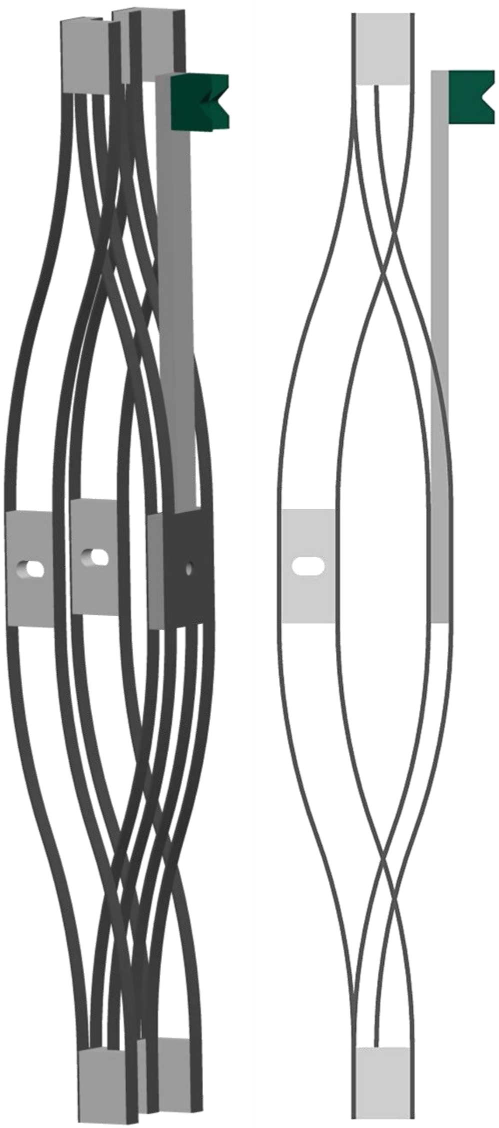
- Driving force in travel direction depending on bending stiffness of flexure
- Disturbing forces:
  1. ***Friction forces*** in defocus direction due to nature of lever-flexure-contact and in lateral direction due to limited lever constraints (e.g. play of bearings)
  2. Gravity force of flexure
  3. Rotational forces / moments due to limited accuracy of lever contact surface and contact point offset
  4. Forces induced by fiber



Optimization of flexure design:

- Higher stiffness of flexure not necessarily decreases position errors since friction forces linearly scale with bending stiffness
- Influence of fiber induced forces is definitely reduced for stiffer flexures
- Low friction contact mandatory (e.g. polished Sapphire – steel contact)

Optimized Flexure Design



- Double blade flexure with highly improved constraints for “parasitic” deflections
- FEA study to optimize flexure geometry based on analysis of friction forces:

		ΔZ	Rot T	ΔT	Rot Z
Spacing between outer leafs	↗	+	+	+	+
Leaf thickness / number of leafs		o	o	o	o
Flexure width	↗	o	o	+	+
Length of flexible sections	↗	+	+	+	+
Middle bridge height	↗	(o)	(+)	(-)	(o)
E-modulus		o	o	o	o
Poisson Ratio	↘	o	o	+	+

+ positive impact
o negligible or no impact
– negative impact

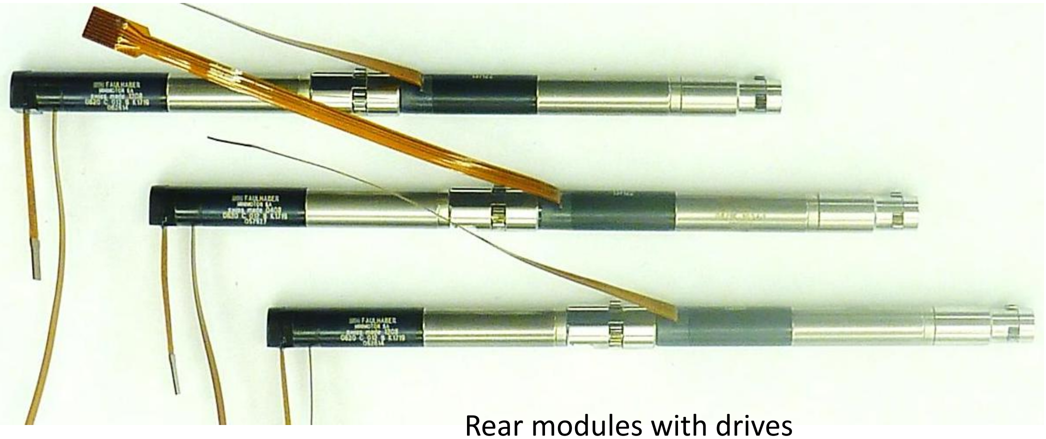
- New set of flexures with ±15 µm defocus (FEA) is currently being built
- Increased width of new flexure requires housing with ~12 mm OD ⇨ front-side insertion

Actuator Prototype Assembly

- 3 of 5 prototypes assembled and integrated in focal plate dummy

Transfer gears

Extension for gearhead shaft



Rear modules with drives

Actuator Prototype Assembly

Core of front module

Cams with hollow shaft

Housing with single-blade flexure

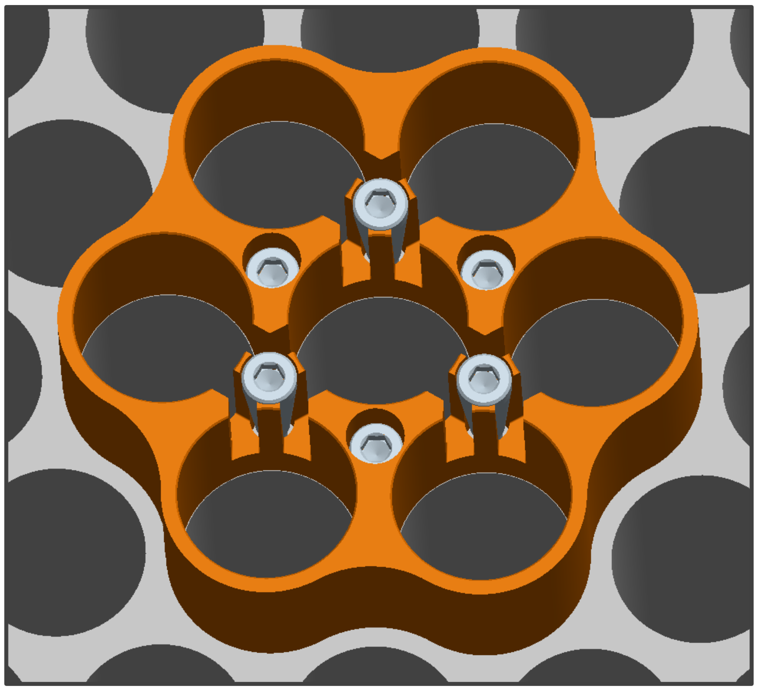
Front and rear module

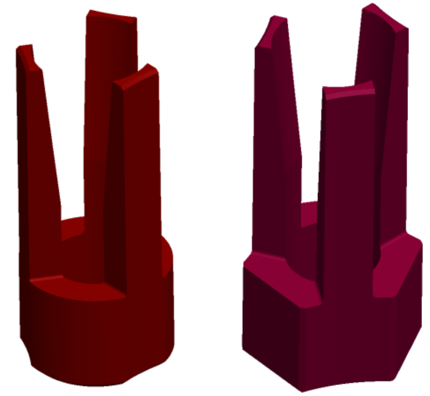
Clamping Prototypes

- Prototypes of two different flexure concepts working very nicely: No noticeable gaps between positioner and clamp, firm grip
- EDM (thin slits) or castable clamping features
- Tapered screw engages central hole
- Alignment and stabilizing pin holes on opposite face

Further Clamping Concepts

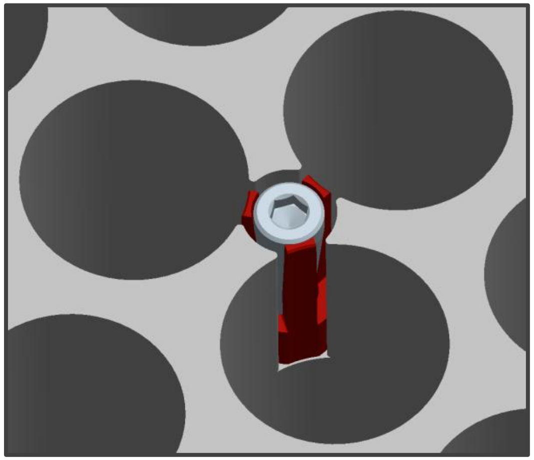
- Clamp for 7 (or more) positioners admits additional mounting bolts
- Inserts: deal much better with focal plate curvature





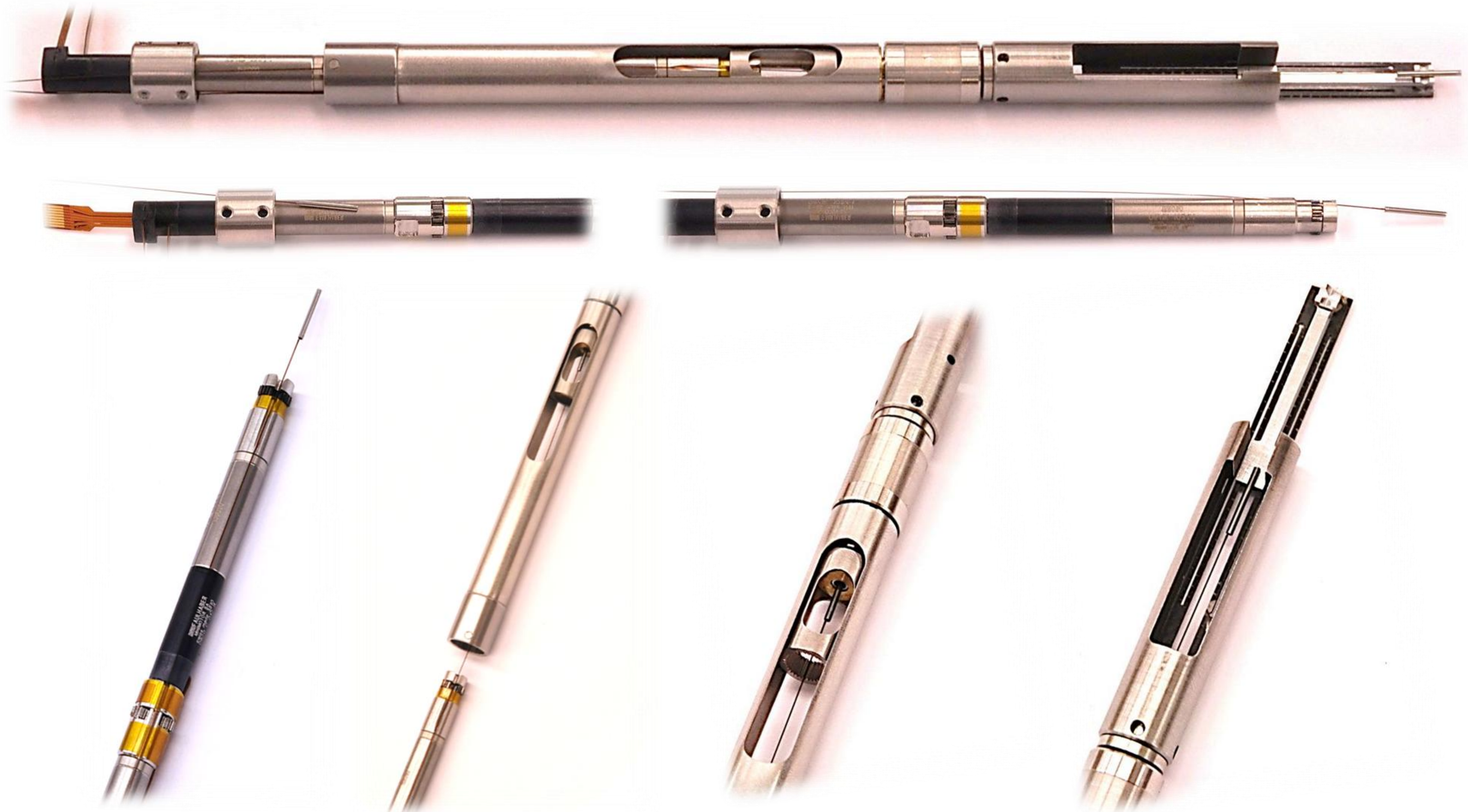
non-clocking design

clocking design



Fiber Threading

- Very facile and fast procedure



Conclusions and Outlook

- First prototypes of R-θ-Actuator assembled and ready for start-up and testing
- Means for characterization of single components and positioner on hand
- Single component testing:
  – NMB bearing cartridges perform excellent
  – Currently integrated single-blade flexure not properly constraint
- New double-blade flexure as replacement for existing flexure currently being built